I. Scholarly Framework

1. Title

Design Evaluator: Sketching Interface with Design Evaluation

Keywords: freehand sketching, design process, evaluation, post occupancy evaluation (POE), wayfinding, time-sequence representation, knowledge-based system, visualization, spatial relation, user needs, text, drawing

2. Thesis Statement

This thesis explores the potential of design evaluation activities in a computer-based freehand sketching environment. Designers use graphical symbols and diagrams in their drawings to generate and develop design-solutions, and communicate with others as well as themselves. Designers make freehand drawings of possible design options until they decide upon the final design solution. In the decision-making process, a design evaluation or feedback stage process accompanies the production of drawings. Therefore, a useful design environment should provide designers with interactive feedback about their design. This research examines the potential of design evaluation and develops an intelligent sketch environment that supports design evaluation activities.

3. Theoretical/Conceptual Framework

3.1 Post Occupancy Evaluation and Evaluation during the Design Process

Architectural designs, particularly buildings, are the subject of evaluation with such methods as architectural criticism and Post Occupancy Evaluation (POE). In architectural criticism buildings are subjects to evaluate with personal eyes. In other words the critics evaluate the buildings based on the related the text and the context. However the basic evaluating ruler is his/her eyes.

The idea of POE is that buildings should consider the needs of the people who use them. The practice of POE is to perform an evaluation of a building design after occupancy (Zimring and Reisenstein 1981). The benefit of POE is that the results can serve as design guidelines for future buildings with similar purposes. If relevant information is available in the design process, designers will find the design solution more effectively. POE enables designers to

easily imagine what human experience is like in a particular space and quickly determine whether or not their designs will work.

Another kind of evaluation, usually less formal than POE takes place during designing. POE is performed after occupancy. In contrast to POE, every decision that is made in exploring design alternatives can be called the evaluation or feedback process of design. Design process is the major focus of design research. Some researchers have considered design process as the problem – solution process (B. Lawson 1994, Cross, Dorst and Roozenburg 1991).

Design problem can be found exactly through analyzing a set of the proposed design solutions. This analyzing process has the features of evaluation in exploring design alternatives. In the early stages of a design process, designers have many design alternatives. As design constraints are added through evaluation and feedback process, designers narrow the design solution space and can find the design solution. Therefore evaluation is essential in the process of finding design solution and this kind of feedback makes design process iterative. Supposing that the cases learned from POE and the design constraints needed in the design evaluation are combined with the design drawing environment, designers can find design solution effectively.

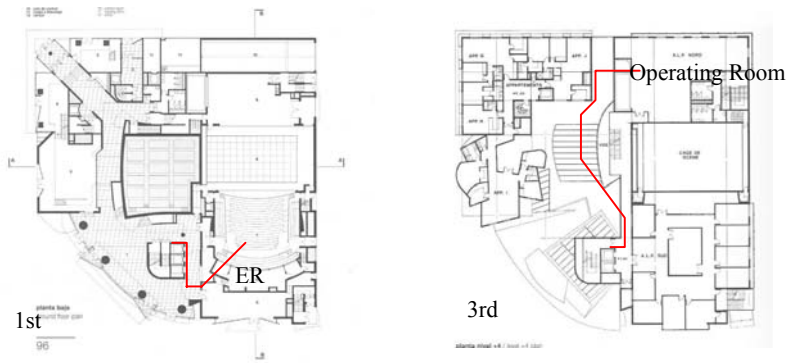
3.2 Scenario

Imagine that Jin, an architect is designing a hospital. Her assistant, Design Evaluator, waits for the proper time to help Jin. Jin represents her ideas by creating a bubble diagram or plans and labeling the spatial functions and names on her drawings (see Figure 1). Design Evaluator recognizes the spatial relations, labeled names and functions.

Figure 1 Sketching the plan in the sketching interface

If Jin would like to rethink or evaluate the spatial relations, Design Evaluator shows the result of evaluation in the format of text and analytical drawing (see figure 2). For example Design

Evaluator can examine the paths from one space to another. The text can show Jin the sequence of the space names, and the analytical drawings can show her the flow of human movements.



Emergency room – corridor (1st floor) – elevator – corridor (3rd floor) – reception desk in small hall for going patient ward – operating room

Figure 2 Analytical Drawings and Text as Evaluation Result

In the text evaluation, Jin can learn of any omissions or mistakes in the spatial arrangement. The more complex the architectural plans are, the more frequently designers overlook the mistakes in the plans. As shown in Figure 2, to reach the operating room from the emergency room, the building occupants have to pass the reception hall. However, this spatial arrangement is unnatural, because the seriously ill patients who need emergency surgeries should be immediately taken to an operating room. In other words, passing the crowded reception hall for getting to the destination is not efficient or appropriate for medical care. The people in the reception hall also probably do not need to experience that kind of emergency condition.

In the analytical drawings, Design Evaluator shows the result of checking the designs. All buildings

Especially in case of hospital, the access of handicapped persons should be considered. For the access of handicapped person with wheelchair, the width of corridor, ramp, and stair, the size of door and elevator are checked by Design Evaluator.

Meanwhile, Design Evaluator shows three dimensional images of the designed space (Figure 3). This provides two kinds of advantages: It overcomes the limitation of 2D graphic drawings and it shows views of the spatial constituents successively like time-ordered human

experiences in the built environment.

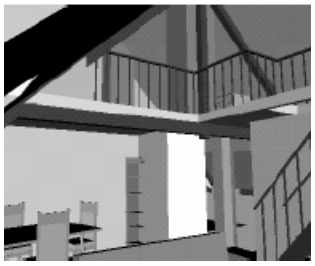


Figure 3 Series of 3D images of the designed space

After recognizing the drawings and analyzing the architectural symbols and taxonomy, Design Evaluator helps Jin in another way; to call up some guidelines in the expert system and similar cases in the case-based system. Jin finds the useful cases and guidelines provided by Design Evaluator and apply them to her design. Jin can go back to her drawing and change her design or explore other design alternatives until she finds out the final design-solution.

3.3 Design Evaluator

Design Evaluator aims to provide a freehand sketching design environment that provides feedback and evaluation in the design process. Designing is often seen as a problem-solving (Cross, Christian, and Dorst 1996, Herbert 1996) and iterative process. Designers create many sketches and drawings in order to search for design alternatives (Lawson 1994).

Design Evaluator has two main components: a sketch-based interface (Do 2001) and a design evaluation advisor. The sketching component is based on VR Sketchpad (Do 2001). The sketch interface supports symbol and diagram recognition. Designers can draw different shapes and label them with functional names. Once the sketch interface recognizes the functional names and design intentions, the design evaluation advisor provides evaluations. It offers two kinds of assistance: (1) visualization of spatial aspects and (2) evaluation from stakeholder's viewpoints (users, designers, etc.) in the format of text and analytical drawings. The Design Evaluator's visualization component shows the flow of movement from one place to another while displaying text and drawings. The drawings show the circulation path superimposed on the floor plans. The text shows the sequence of space names (functional names of the spaces). Analytical drawings generated by the design evaluation advisor display the evaluation results in a perspective view based on a sequence of viewpoints on the path. These 3D architectural perspective views provide a visual experience of the designed space.

This is an important feature because people of the explain the built environment through the flow of movement (Thiel 1997). Evaluation from stakeholder's viewpoints is important feedback in the whole design process. Several researchers have investigated ways to visualize and represent multi-stakeholder interests (Gross 1997, Domeshek, Kolodner, and Zimring 1994).

The Design Evaluator also provides design guidelines at the appropriate time in the design process. For example, once the system recognizes the name of the room or functional space, the system uses that information to retrieve the relevant building codes or architectural standards (planning rules, ergonomic rules) from an expert system. For example, in designing a hospital, a designer may start by making conceptual diagrams and drawings using many symbols and texts. The drawings could include architectural symbols (step, elevator, and door) as well as the names of rooms (emergency room or operating room). The Design Evaluator would then recognize the drawings and perform design evaluations. In summary, Design Evaluator has two main purposes: 1) facilitate the feedback loop of the design process by providing visualization and related information 2) help designers recognize potential design problems and offer design guidelines selected from the expert system. Design Evaluator has an embedded knowledge-based system for design evaluations. This knowledge-based system is a database of building codes and architectural standards. The system detects potential problems and provides the evaluation and feedback once the design's drawing and labels are recognized.

Figure 4. shows the system architecture of the Design Evaluator. The designer interacts with the system through the sketch-based Interface. Using a symbol definition library the Design Evaluator recognizes the designer's drawings (Recognition System). Then an Expert System

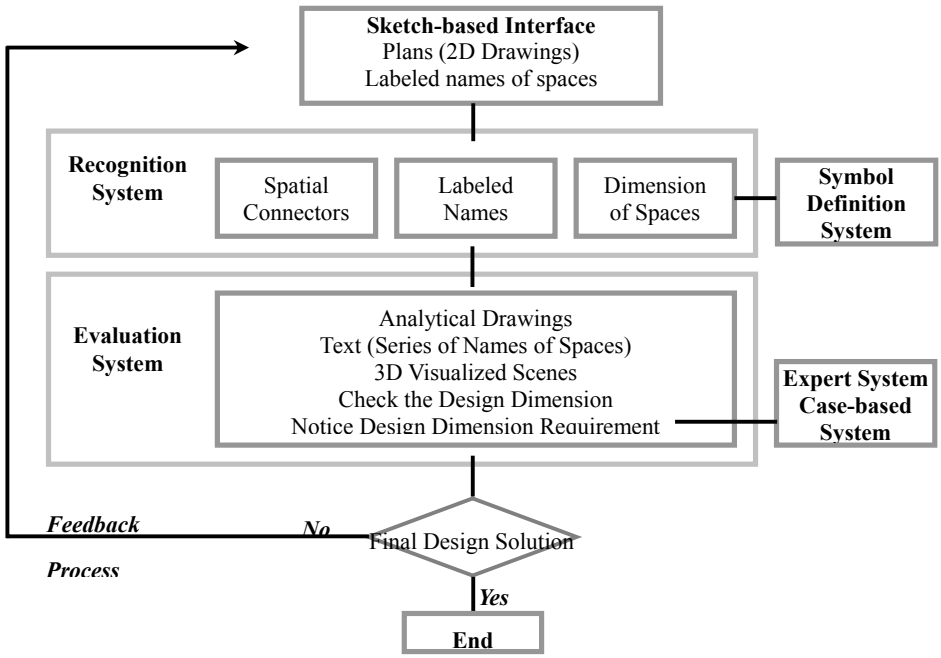


Figure 4 the System Architecture of Design Evaluator

- **Sketch-based Interface**

  The Sketch-based Interface allows designers to make freehand drawings in the sketch board. In this environment, designers can explore the design alternatives with 2D drawings – plans. Designers can represent the space arrangement using several symbols (wall, door, and label the names in the drawings.

- **Recognition System**

  For evaluating the designed plans, this system should recognize the connectors between spaces, labeled texts and dimensions. There are two kinds of connectors: horizontally, doors and vertically, elevators and stairs. Through recognizing these connectors, evaluation system can show the analytical drawings and text (series of space names). For calculating dimensions of spaces, this system needs a scale feature. The door can be a scale feature especially in 2D drawings. After finding the size of door, the system can calculate the relative dimensions of spaces in the freehand drawings.

- **Symbol Definition system**

The symbol definition system allows designers to establish a pre-defined symbol template that provides information for the symbol recognizer, for example door. Designers draw a symbol in the sketch window, and then define the symbol in the symbol definition window.

- **Evaluation System**

  The System shows the result of evaluation in several ways: analytical drawings, text, 3D scenes, and notice of spatial dimension errors. Analytical drawings show the circulation from one space to another space. In text format, a series of spaces from one space to another space can be shown. In the shown path, spatial dimension can be calculated and then checked for mistakes.

- **Expert System**

  If the evaluation process reveals spatial dimension errors, system provides designers with architectural standards and building codes as design guidelines.

- **Case-based System**

  Case-based system provides designers with design assistance by providing past design precedents. Through this kind of help, similar mistakes may be prevented from happening again and the precedents can be applied to other design problem.

4. Methodology

This thesis presents Design Evaluator, a computer drawing tool with design feedback and evaluation for design decision making help in the design process. Design Evaluator is based on the study of the role of freehand drawings in architectural design, evaluation of designs and knowledge-based systems. Through these theoretical studies, I will form the basis of my argument. Through implementing this system I will demonstrate whether or not this system can help designers in the design process.

5. Preparatory Study

I prepared part of my thesis project during the several course: Digital Computing Theory, several independent studies, and Design Computing Seminar. First “Digital Computing Theory” gave me theoretical backgrounds- design thinking and design process. I also received some background knowledge including the sketching interface

and prepared the programming ability to implement the design evaluator system.

6. Annotated Bibliography

- The Roles of Drawings in the Design Process

Architects use drawings to externalize design ideas using graphic signs and symbols, develop their design, and communicate with people.

Architects usually draw diagrams and sketches to externalize design ideas using graphic signs and symbols. Psychology research emphasizes the role of visual thinking in the creative process. What plays a role in mechanism of thought is not word and language but visual images and signs. Design consists of a creative component as well. Usually a designer's media to create product is drawings, freehand sketches. Designers draw graphic signs to represent the visual images in their mind.

Designers develop their design ideas and find design solution by drawing diagrams and sketches continuously. Designers add new ideas and modify previous designs by subtracting or adding to the design. As illustrating Figure 5, information of design is cycled in the design loop from paper to eye to brain to hand and back to the paper. In other words visual images in mind are reexamined and rearranged on the paper by drawing a sketch. This loop has design information and provides designers with design developing opportunities.

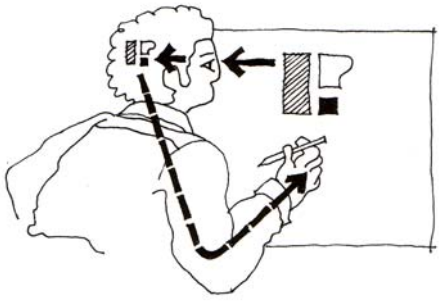


Figure 5. Design Thinking

Architects communicate with other people, co-workers and stakeholders with drawings. While designers work together in the design process, they need to share information to generate design solutions with a common concept. The initial concepts become more detailed and more

robust in the design process until the final design solution is achieved. In this process, the mode of communication is both verbal and graphical. The role of this visual-graphical mode is very important in order to communicate with other people.

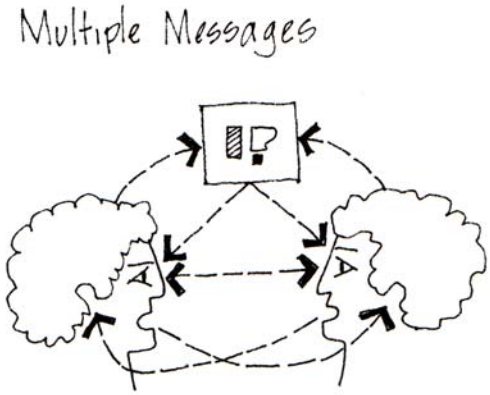


Figure 6. Communication with Drawings

Peter Engel, Folding the Universe : origami from angelfish to zen, New York : Vintage Books, c1989

Research of psychology field emphasizes the role of visual thinking in the creative (inventive) process. What play a role in mechanism of thought is not word and language but visual images and signs.

E. Do, The Right Tool at Right Time: Investigation of Freehand Drawing as an Interface to Knowledge based Design Tools, PhD, Georgia Institute of Technology, 1998

P. Laseau, Graphic Thinking for Architects and Designers, New York, Van Nostrand Reinhold, 1989

Architects use drawings to externalize design ideas using graphic signs and symbols, develop their design, and communicate with people.

E. Robbins, Why Architects Draw, Cambridge, MIT Press, 1994

D. M. Herbert, Architectural Study Drawings, New York, Van Nostrand Reinhold, 1993

E. Do, Functional and Formal Reasoning in Architectural Sketches, Sketch Understanding, Papers from the 2002 AAAI Spring Symposium Technical Report SS-02-08, AAAI Press, 2002

I. Fraser and R. Henmi, Envisioning Architecture- an Analysis of Drawing, New York, Van Nostrand Reinhold, 1994

Edited by Nigel Cross, Kees Dorst, Norbert Roozenburg, Research in Design Thinking, Proceedings of a Workshop Meeting held at the Faculty of Industrial Design Engineering Delft University of Technology, Netherlands, 1991

The design process how people do design, is the major part in design research. The purpose of this article is reviewing research methods and research results about design thinking. There are the six ways to research design thinking; interview with designers, observations and case studies, protocol studies, controlled tests, simulations trials, and reflections and theorizing.

Through these research methods, researchers got the result that there are 3 patterns in the design process, Problem Formulations, Solution Generation, and Cognitive Strategies. The nature of the design problem can be found through analyzing a set of proposed solutions (alternative solution conjectures), because the relation of between the problem and solution is "conversational". Designers then narrow the solution space by adding some constraints, called the "missing ingredient". In this process, the design task goal continues to be changed and constraints continue to be redefined, but designers keep the "major solution concept" as long as possible. Changing the goal and constraints continuously is in order to avoid the difficulty of starting with a new concept. Finally, designers think the design problem is ill-defined, and they use a solution-focused cognitive strategy.

B. Lawson, Design in Mind, Oxford, Butterworth, 1994

This article put more emphasis on design process than on end-product. To understand the design process, the author said that we have to use all the methods we can; analyzing the task and proposing logical structures and processes, observing designers at work, conducting lab experiments on designers, and asking designers to tell us what they do.

The author regards design process as a "sequence of cognitive operations"; assimilation-

analysis-synthesis-evaluation-communication. This design sequence is repeated with a feedback loop to generate design solution. In the design process an understanding of the user's feeling is also necessary for designers, and technologies can have some affect on the design process.

B. Lawson, How Designers Think, Oxford, Butterworth, 1998

This article is focused not on end-products but on the design process. The author gives an attention to why the design processes are different in other areas, for example engineering and dress designing. He said that it is not because the design problem is different but because the approach method to the design problem is different.

Design activities are a well-organized mental process, making various kind of information based on art, society and technology to a coherent set and showing the designer's thoughts.

- **Time-Sequence Representation**

Drawing is an effective tool to generate and communicate designs with others. Architects draw several kinds of drawings. Among the various types of drawings architects make, the majority are 2D drawings, such as, plan, section and elevation. When architects draw sketches to represent different design intentions, they use different architectural conventions. Architectural conventions have several manners: different colors and different types of lines mean different spatial characters, specific symbols mean space shapes or characters, and short texts labeled on the drawings are for the space names (functions) or short comments related to designs. Drawings can represent visual information in the mind, all information can be shown simultaneously. For example, an architect views, he or she sees the whole spatial configuration, such as where a specific room is and what room is located beside that room. In contrast to human experience, the visual form on the drawings takes another way of information representation. People's experience in the built environment is time-ordered, and successive. When we enter the buildings, we get the visual images of the buildings' constituents successively. People cannot get the imaginary map in their mind until they have stepped directly on all the spaces in the building.

Architectural drawings are very different from human experiences in the built environment. Architectural drawing is essentially representational, whereas humans experience or thinking mechanism is time-ordered, discursive.

Drawings are a strong and useful medium in visual thinking. However, drawings have a couple of limitations. First, considering that human experience is necessary in design process, because architectural design is to make spaces where people live. Unfortunately, drawing and human experience have different representation methods: symbolic vs. time-sequenced. Therefore we need another way to support the design process besides drawings. This reminds us of our experiences in the built environment. We remember visual features in the sequence of visual scenes through our walkthrough.

Second, drawings cannot represent completely vague or nebulous design ideas formed in the internal thinking mechanism. Some spatial information must be missing, because visual symbol is basically representational. For example a plan can show the spatial design in the specific viewpoint, even plan with section and elevation supplementing plan is too specific to manipulate flexibly to explore various design alternatives. Even trained designers can sometimes encounter difficulties in imagining a space using 2D drawings. Generally the mode of design is not only drawing but also a verbal mode. Verbal and graphic modes support each other and are interdependent.

Therefore, we need to explore another tool to fully support design process more completely. If a computer design tool can provide designers with successive scenes of a designed environment and a series of short text, the previously mentioned limitations can be overcome.

Charles Rusch and Stuart Silverstone, The Medium is Not the Solution, AIA Journal, Dec. 1967

Donald Appleyard, Understanding Professional Media, in Irwin Altman and Joachim F. Wohlwill, eds., Human Behavior and Environment, New York: Plenum Press, 1977

In this article the author divides the design and planning process into 3 stages: analysis of the existing environment, design generation, and presentation and public communication. He also emphasizes the role of simulation. In my opinion, we can consider that showing sequential scenes of designed spaces and series of spaces in the text have the same identical concept with simulation. He describes the roles of simulation in the each design stage: to simplify, select, and coordinate from a mass of information whatever is relevant to the design or the planning decision, to be manipulatable as new ideas and information to enter the process, and to sell the decided-upon proposal, or to persuade the public of design's value. Here I'd like to discuss the first and second roles: through simulation, designers can manipulate spatial information in the

decision making process. This manipulation includes the addition of new design ideas, subtraction of old design idea, modification of current designs, etc.

Donald M. Herbert, Study Drawings in Architectural Design: Their Properties as a Graphic Medium, Journal of Architectural Education, Winter 1988

George E. Mckechnie, Simulation Techniques in Environmental Psychology, in Daniel Stokols, ed., Perspectives on Environment and Behavior, New York: Plenum Press, 1977
The author describes the property of experiencing environment and categorized the simulation to 4 types. He noted that people experience the built environment discursively or time-based discursively. In other words, people can get the series of scenes and visual features through path or walkthrough in the environment. He categorized simulation types, using two dimensions: conceptual-perceptual and static-dynamic.

Philip Thiel, People, Paths and Purposes, Notations for a Participatory Envirotecture, University of Washington Press, Seattle and London, 1996

Susanne Langer, Discursive and Presentational Forms, in Philosophy in a New Key, Cambridge: Harvard University Press, 1942
The author compares the visual forms (lines, colors, proportions, etc.) with language. Thoughts in the mind are arranged in a peculiar order that can be spoken and written. We call this peculiar order syntax. Verbal symbolism has "discursive" property. On the other hand, visual forms also have a complex mechanism, but that is different law of syntax. Visual forms show information simultaneously but show its constituents successively. Visual forms have "articulation" property.
Here the related theoretical background with this thesis is found. She noted the "picture language" – using separate pictures in place of words. Pictures made by visual forms are presentational, but the written words help to limit the "presentational" property. She describes this picture language as "discursive symbolism".

- **Wayfinding**

While people live in a building, the most common behavior is perhaps wayfinding or teaching the way to others. This behavior is deeply rooted in human spatial cognition. When someone

visits a certain building for the first time, he or she locates a map in the front lobby or ask others to assist him or her in finding their destination. Using this information, someone overcome the difficulty in locating the way to his or her destination, depending on the individual's spatial cognitive ability (Hunt 1985). After people became familiar with the built environment, they can recall on their own the whole layout of the building and find the way from one place to another.

How do people recall the layout of the built environment? To answer this question, remember the situation of explaining wayfinding to strangers. Perhaps the easiest way of describing the built form is by referring to the suggestive idea of a landmark (Lynch 1960 and Mandler 1988) and the configuration between spaces. Like urban context in Lynch's theory, in complex buildings, many things from visual characteristics to formal distinctiveness or functional importance may act as landmarks. Spatial configuration means the overall layout of spaces, for example spatial relation, and the relative distance with two spaces. Spatial configuration can be obtained by a collage type of visual experiences (Tversky 1993), which allows us to encode and retrieve spatial information in using the mind's imaginary map.

John Peponis, Craig Zimring, Yoonkyung Choi, Finding the Building in Wayfinding, Environment and Behavior, Vol. 22, No. 5, Sep. 1990, p 555-590

Kevin Lynch, The Image of the City, Cambridge: MIT Press, 1960
Perhaps the easiest way of describing the built form is referring to the suggestive idea of a landmark. Like urban context in Lynch's theory, in the complex building many things from visual characteristic to formal distinctiveness or functional importance may act as landmarks.

M. E. Hunt, Enhancing a Building's Imageability, Journal of Architecture and Planning Research, 2, p 151-168, 1985
Nevertheless visual help or others' phonetic help, someone can meet the difficulty to find way to his destination depending on individual's spatial cognitive ability

S. L. Golbeck, Spatial cognition as a Function of Environmental Characteristics, The Develop of Spatial Cognition, Ed. Cohen, R. Hillsdale, Nj: Lawrence Erlbaum Associate, 1985.

J. M. Mandler, The Development of Spatial Cognition: on Typological and Euclidean Representation, Spation Cognition: Brain Bases and Development. Eds. Stiles-Davis, J.M. Keritchensky and U.Bellugi. Hillsdale, Nj: Lawrence Erlbaum Associates, 1988

B. Tversky, Cognitive Maps, cognitive Collages and Spatial Mental Models, COSIT '93, Marciana Marina, Elba Island, Italy, Sep. 1993. Eds. Frank, A. U. and I. Campari. Springer-Verlag. 1993

This spatial configuration can be obtained by the collage type of visual experiences and this allows us to encode and retrieve spatial information in the mind's imaginary map.

- **Knowledge-based System**

Knowledge-based systems have wide acceptance in computer-aided design systems (CAD). The current CAD system cannot provide designers with helpful advice in the process of solving design problems, because it cannot express the internal reasoning and judgment process that exists in each design decision stage.

Expert systems help design decision making by giving design rationale or design guideline (Maher 1985, Pohl and others 1988, Rittel and Kunz 1970). On the other hand case based systems provide designers with design aid through giving past design precedents (Kolodner 1991, Oxman 1993, Zimring and others 1994). Through this kind of help, similar mistakes may prevent from being happened again and the precedents can be applied to other design problem.

Kolodner, Janet, Case-based Reasoning, Morgan Kaufmann Publishers, Inc, 1993

Case-based systems help solve the new problem with previous situations. The previous cases are used to provide a means of solving the new problems, suggesting a means of adapting a solution, warning of possible failures, and interpreting a situation. Case based reasoning helps design process in the several ways: adapting old solutions to meet new demands, using old cases to explain new situations, using old cases to critique new solutions, reasoning from precedents to interpret a new situation, and creating an equitable solution to new problems.

May Lou Maher, Hi-Rise and Beyond: Directions for Expert Systems in Design, in Computer Aided Design, p 420-426, Butterworth & Co, 1985

Pohl, Jens, Art Chapman, Laurian Chirica, and Leonard Myers, ICADS - toward an Intelligent Computer-aided Design System, CAD Research Unit, School of Architecture and Environmental Design, California Polytechnic State University, San Luis Obispo, CA 93407, 1988. Design Institute Report CADRU-01-88

W. Rittel and W. Kunz, Issues as Elements of Information Systems, Center for Planning & Development Research, University of California, Berkeley, 1970, p 131.
Janet L. Kolodner, Improving Human Decision-making through Case-based Decision Aiding, *AI Magazine* 12, 1991, p 52-68

R. E. Oxman, Case-based design support: Supporting architectural composition through precedent libraries, Journal of Architectural Planning Research, 1993

Craig Zimring, Ellen Yi-Luen Do, Eric Domeshek, and Janet Kolodner, Using postoccupancy evaluation to aid reflection in conceptual design: Creating a case-based design aid for architecture, In Design Decision Support System, ed. H. Dimitripoulos. II. Vaals, Netherlands, 1994.

II. Logistical Framework

1. Outline of Tasks

- Literature Review: I will summarize the theoretical background: the role of drawings in design, time-sequence representation, design evaluation and post-occupancy evaluation (POE), wayfinding, and knowledge-based systems. Literature review will be described to serve as the background knowledge for the thesis. I will also provide my own interpretation and discussion of each theme.
- Related work: I will explain the research projects related with this thesis. I will discuss the limitation of the related work, how these related work connect with my thesis.
- Design Computational Part: I will describe the implementation of the Design Evaluator System.

2. Schedule

8-10 weeks in Spring 03: to research related work, to learn LISP programming

Summer: to research literature review and related projects

Summer - 4 week in Autumn 03: implementing the interface

4 week – 7 week in Autumn 03: modifying the interface and writing documents

3. Available Resources

Faculty Support: Ellen Yi-Luen Do and Mark D Gross

4. Space Support

MS program in the dept of architecture (Design Machine Group) will provide the thesis space during autumn quarter.